# Performance of DPFC using ANN and Comparison with PI Controllers

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***Abstract*** **- Power flow is limited by the control of active power in current power systems using different controlling techniques and power flow controlling devices. Flexible AC Transmission Systems (FACTS) are a revolutionary innovation in the area. Distributed Power flow Controllers (DPFC) are novel variants of Unified Power flow Controllers (UPFC) and a class of FACTS devices which control various parameters like voltage of the buses, impedance of the transmission line, phase angle adjustment between sending and receiving end voltages. The operation of the shunt converter does not relate or depend on the operation or working of series converter due to the absence of dc link in case of DPFC. The design of series converter is based on distributed concept of modeling of FACTS controllers. The reliability of the transmission system and minimization n of the overall cost is achieved by the use of individual single phase converters in contrast to the traditional three phase converter. The DPFC configuration is based on the transmission line enabled exchange of active power in the system which predominantly occurs in at 3rd harmonic frequency order. Single phase to ground voltage applied to the converter of the DPFC, eliminates the need for isolation of high voltage components. Therefore, the reduced cost of economics is an added advantage for DPFC unlike UPFC. The various control strategies are advocated for the control of novel FACTS technology devices. Among them, we have considered proportional integral controller and artificial neural network based soft computing technique and the preferred control technique is determined in this paper.**

***Keywords - Flexible AC Transmission System, Distributed Power Flow Controller, Current Control, Power Flow Control, symmetrical component, Voltage Source Converter***

## I. INTRODUCTION AND BACKGROUND

Renewable or non conventional energy resources are need of the hour in the 21st century power system generation in order to meet the customer power requirements [1]. Therefore, the conventional energy systems tend to act or function as secondary sources, utilizing the renewable or non depleting energy reserves to the fullest extent. Therefore the regulation of the power influx and out flux is necessary and inevitable in the changing system dynamics [2]. The regulation of instantaneous power flow across the line involves variation of the transmission line parameters line impedance of the line, angle between source and load voltages, and the magnitude of the voltages. These devices which facilitate the regulation of power are power flow controlling devices (PFCD). The FACTS technology should be interfaced with the PFCDs in order to achieve accurate power flow [3]. Among the PFCDs, UPFC (Unified Power Flow Controller) is one of the commonly used for power regulation. The main feature of UPFC is voltage injection with setting or varying the magnitude and angle in series mode and is done by the series converter of UPFC [4]. Figure 1 demonstrates the arrangement of the DPFC comprising of shunt and arrangement associated converters as if there should be an occurrence of UPFC. Every converter inside the DPFC is free having its own particular DC capacitor that gives the required DC voltage. Other than shunt and arrangement converters, DPFC additionally needs a high pass channel associated parallel to the other side of the transmission line and on each side of the line there is a star delta transformer [4].

There are two noteworthy points of interest of DPFC contrasted with UPFC: 1. Low voltage seclusion and the arrangement converter's low part evaluating causes minimal effort and 2. The pointless of the arrangement converters causes high unwavering quality. In this paper section II gives the principle of the DPFC. Section III tells the control strategy used in DPFC, the section IV gives the simulation results of the DPFC.

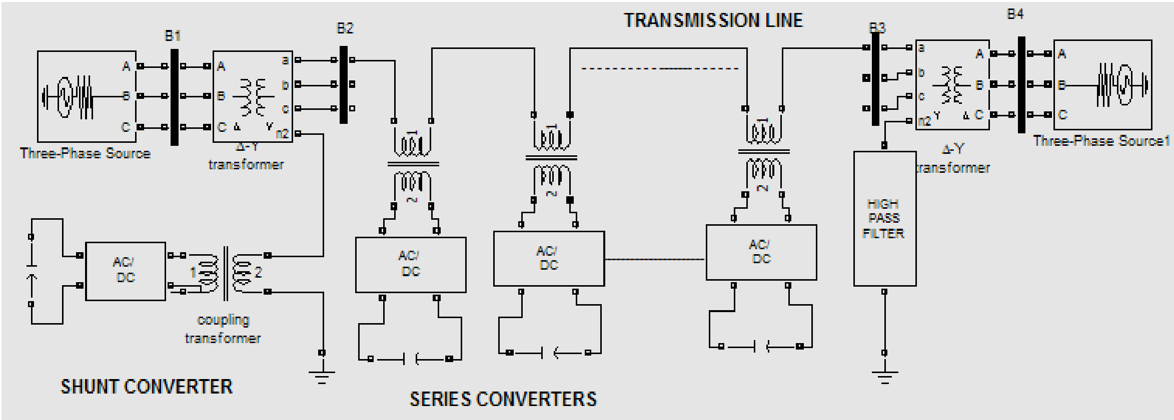


Fig. 1. Distributed power flow controller.

## II. DPFC PRINCIPLE

The transmission line is the normal association between the air conditioner terminals of the shunt and the arrangement converters through which dynamic power is traded. In Fourier investigation the non sinusoidal current and voltage is communicated by the whole of sinusoidal capacities in various frequencies with various amplitudes [5].The power hypothesis of non sinusoidal segments is utilized as a part of the strategy.

The dynamic power can be communicated as in condition [1] as the integrals of all the cross result of terms with various frequencies are zero.The dynamic power that outcomes from the non sinusoidal current and voltage is characterized as normal estimation of the result of voltage and current.

$$P = \sum_{i=1}^{\infty} V_i I_i \cos \emptyset_i \tag{1}$$

Where Vi and Ii are the voltage and current at the ith symphonious harmonic recurrence, individually, and φi is the relating edge between the voltage and current. From condition (1) it is watched that at various frequencies the dynamic power is secluded from each other and the dynamic power at any recurrence isn't influenced by the voltage or current.

The dynamic power is autonomous at various frequencies; this demonstrates the likelihood of a converter without control source producing dynamic power at one recurrence and can retain a similar power from different frequencies. Following a similar technique in DPFC, the dynamic power can be consumed by the shunt converter from the framework at major recurrence and embed a similar current into the network at a symphonious harmonic recurrence.

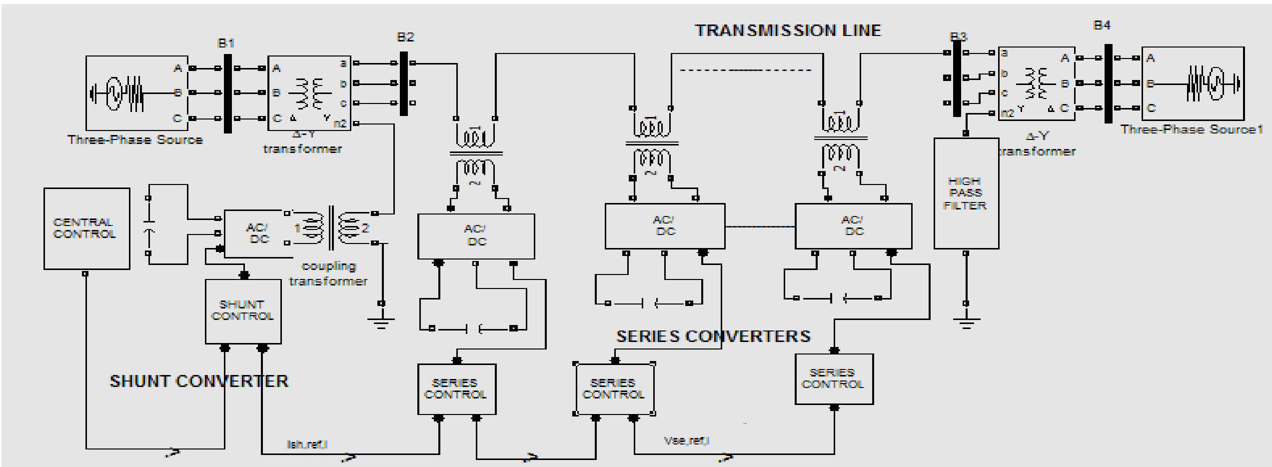


Fig. 2. Block diagram of the control of a DPFC.

This consonant harmonic current will course through the transmission line. In light of the measure of dynamic power that is required at the basic recurrence, the voltage is created by the DPFC arrangement converters at the symphonious recurrence along these lines engrossing the dynamic power from consonant parts. Expecting a lossless converter, the dynamic power produced at essential recurrence and the power retained from the consonant recurrence are equivalent.

The high-pass channel of the DPFC permits the entry of the consonant parts, obstructing the crucial recurrence segments, by that demonstrating an arrival way for the symphonious segments. The shut circle for the symphonious current is framed by the high-pass channels, shunt and arrangement converters and the ground. For the trading of the dynamic power in the DPFC the third symphonious is chosen due to the novel characters of third consonant parts. In a three-stage framework, the third symphonious in each stage is same, which is called as "zero-succession." The zero-arrangement consonant can be normally hindered by Y–Δ transformers, which are broadly utilized as a part of energy framework to change voltage level. Thusly, there is no necessity of additional channel to whatever is left of the system for the aversion of the symphonious harmonic leakage [8][9].

### A. DPFC Control Principle

Fig. 2 demonstrates the three kinds of controllers that control the numerous converters; they are focal control, shunt control and arrangement control. The parameters of shunt and arrangement control are kept up without anyone else's input, they are additionally called as nearby controllers. At the power-framework level the focal control controls the DPFC capacities. The capacity of every controller is recorded in following sections.

### B. Central Control

The fundamental capacity of the focal control is to create reference signals for both the shunt and arrangement converters of the DPFC. These are produced at the key recurrence. The focal control gives responsive current flag for the shunt converter and comparing voltage-reference signals for the arrangement converters as per the framework prerequisite. At the power-framework level, the focal control is reliant on the specifics of the DPFC, they are low-recurrence control wavering damping, control stream control and adjusting of parts which are not symmetric about the axis.

### C. Series Control

Arrangement series control is available in every arrangement converter. The controller keeps up capacitor dc voltage for its own converter utilizing third consonant recurrence segments. It is additionally used to create arrangement voltage at the key recurrence which is endorsed by the focal control. In the DPFC arrangement converter control the significant control circle is the third symphonious recurrence control. For the dc voltage control the vector control guideline is utilized.

### D. Shunt Control

The infusion of the consistent third consonant current into the line keeping in mind the end goal to give dynamic energy to the arrangement converters is the fundamental goal of the shunt control. At the basic recurrence the third symphonious current and transport voltage are bolted. The point of shunt converter is infusing a controllable responsive current to lattice and keeping the dc capacitor voltage at consistent level.

## III. CONTROLLER DESIGN

### A. PI Controller Design

The transfer function for PI controller is defined as:

$$H_{PI}(s) = K_p + \frac{K_I}{s} \tag{2}$$

Where KP is the proportional gain and given by 2.ξ.ωn.C which has an impact of DC voltage control in dynamic system mode.

So also, the necessary pick up is inferred utilizing KI =Cωn2 that decides it's settling time. The PI controller for the DC-interface voltage sets the plentifulness of the dynamic current of the APF inverter to manage the DC-connect voltage in light of its reference esteem covering the inverter misfortunes. Subtracting the deliberate load current, the reference estimation of the APF current is acquired. Thus, KP = 2.ξ.ωn.C and KI =Cωn2, for ξ = 0,707 and C=1100×10-6 F , KP and KI can be resolved.

### B. ANN Controller of DC Voltage

ANN ANN are a group of factual learning models motivated by natural neural system and are utilized for appraise or surmised capacities that can rely upon countless are by and large known ANN are for the most part introduced as arrangement of interconnection neuron which send messages to each other. The associations have numerical weights that can be tuned in light of experience making neural system versatile to information sources and fit for learning.

This paper draws vital on the multi layer sustain forward ANN which that of the non straight multivariable capacity portrayal. The ANN is utilized for the mapping between the distinction of reference DC and Changed Value of DC on DC side of arrangement converter for legitimate working conduction and ideal controller parameter [13][14].

```
numHiddenNeurons = 20;
net =
newfit(inputs,targets,numHiddenNeurons);
net.divideParam.trainRatio = 70/100;
net.divideParam.valRatio = 15/100;
net.divideParam.testRatio = 15/100;
% Train and Apply Network
[net,tr] = train(net,inputs,targets);
```

```
outputs = sim(net,inputs);
% Plot
plotregression(targets,outputs)
```

The following features of ANN make them convenient for usage in majority applications.

Learning by adaptation
Organisation through self
Operation in real time mode

## IV. APPLICATIONS

a) Adaptive learning: An ability to learn how to do tasks based on the data given for training or initial experience.
b) Self-Organization: An ANN can create its own Organization or representation of the information it receives during learning time.
c) Real Time Operation: ANN computations may be carried out in parallel, and special hardware devices are being designed and manufactured which take advantage of this capability.

TABLE-1: MEASURED VALUES OF CONVERTER

| Symbol | Description | Value |
|---|---|---|
| $V_{sh,max}$ | Shunt converter maximum ac voltage | 50 V |
| $I_{sh,max}$ | Shunt converter maximum ac current | 9 A |
| $V_{sh,dc}$ | Shunt converter dc source supply | 20 V |
| $I_{sh,ref,3}$ | Reference 3rd harmonic current injected by the shunt converter | 3 A |
| $f_{sw}$ | Switching frequency for shunt and series converter | 6 kHz |
| $V_{se,max}$ | Maximum ac voltage at line side of the series converter | 7 V |
| $I_{se,max}$ | Maximum ac current at line side of the series converter | 15 A |

TABLE-2: MODEL PARAMETERS

| Symbol | Description | Value |
|---|---|---|
| $V_s$ | Sending end bus voltage | 220 V |
| $V_r$ | Receiving end bus voltage | 220 V |
| θ | Transmission angle between sending and receiving end bus voltages | 1° |
| L | Line inductance | 6 mH |

## V. SIMULATION RESULTS

To recreate the PI controlled DPFC, a model in Matlab/Simulink is created. Reenactment ponders are completed to break down the execution of DPFC in a transmission framework. A basic two transport framework is considered for recreation. Power stream between the two transports is gotten by giving a stage contrast between the transports. DPFC comprises of one shunt converter and six single stage arrangement converters. The shunt converter is a solitary stage converter associated between impartial purpose of Δ-Y transformer and the ground, and is fueled by steady DC source. Here we consider a transmission framework with a voltage of 380V and 50Hz.

Table 1. System parameters in Simulink model DPFC using PI

The voltage infused by the arrangement converter is appeared in fig 4 and the voltage and current at the Δ-side of the transformer are appeared in Fig 8. Figs 5 and 6 demonstrate the crucial parts of arrangement infused voltage and line current individually. It is seen from Fig. 4 that the voltage infused by arrangement converter is a heartbeat width adjusted (PWM) waveform containing two recurrence parts. The sufficiency of the waveform speaks to the dc-capacitor voltage at the line side of the transformer.

The Fast Fourier Transform (FFT) examination is performed on converter voltage appeared in Figs 9 to 11 utilizing FFT apparatus accessible in Matlab to gauge the central voltage infused by arrangement converter.

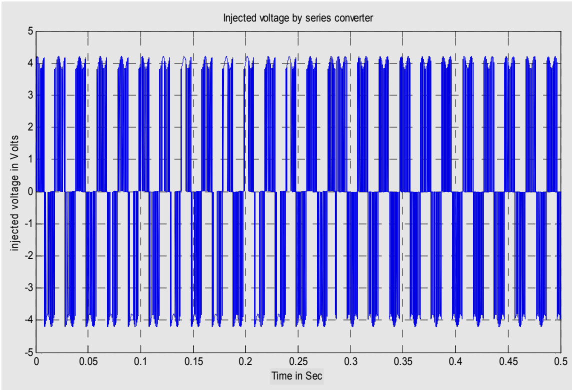


Fig.4 Series converter Injected voltage.

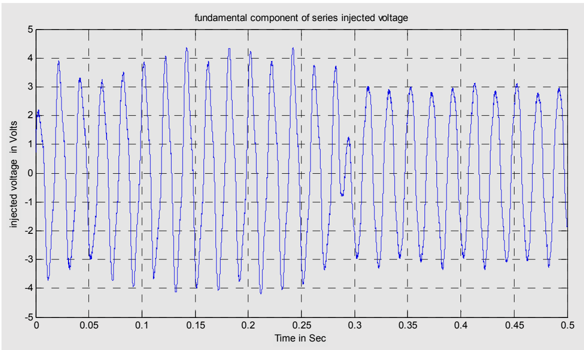


Fig 5. Fundamental component of series injected voltage.

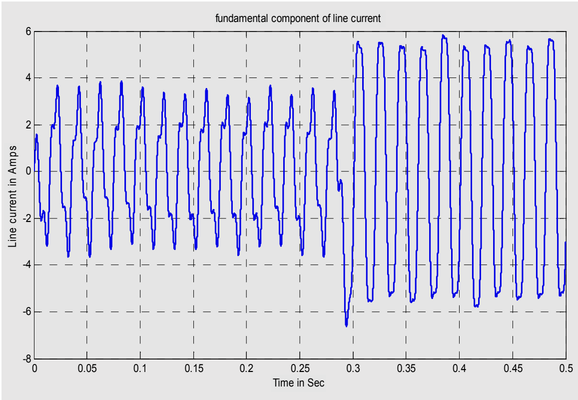


Fig 6. Fundamental component of line current

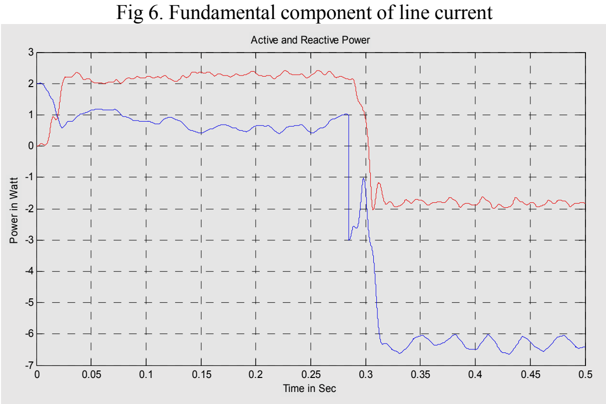


Fig 7. Active and Reactive power.

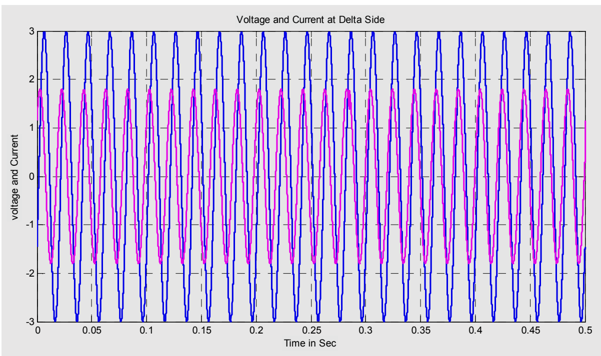


Fig 8. Voltage and Current at Delta side.

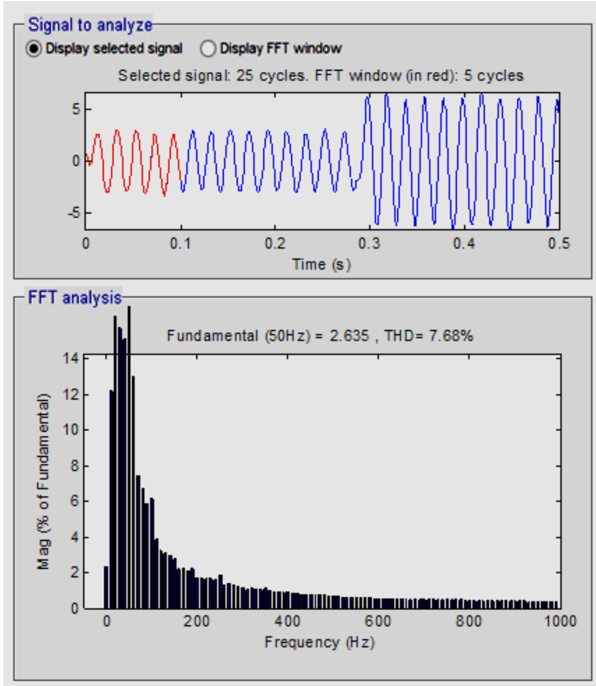


Fig 9. THD analysis - IREC

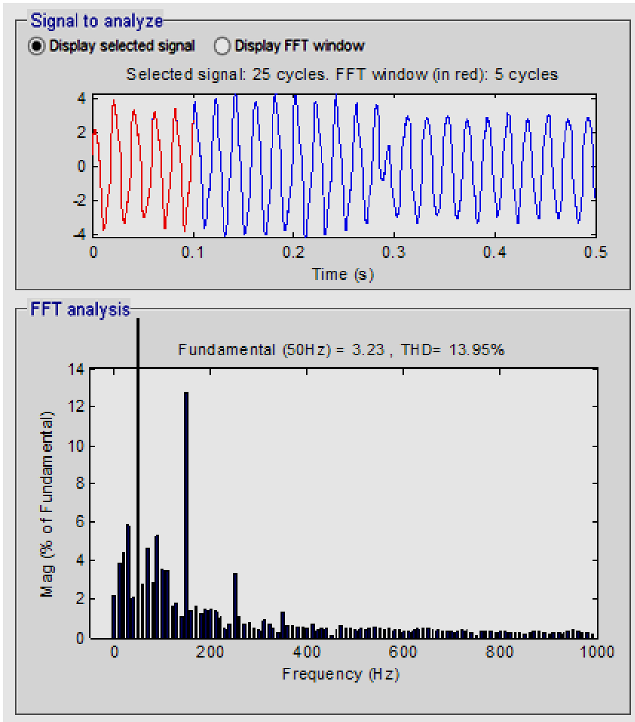


Fig 10. THD analysis – Voltage.

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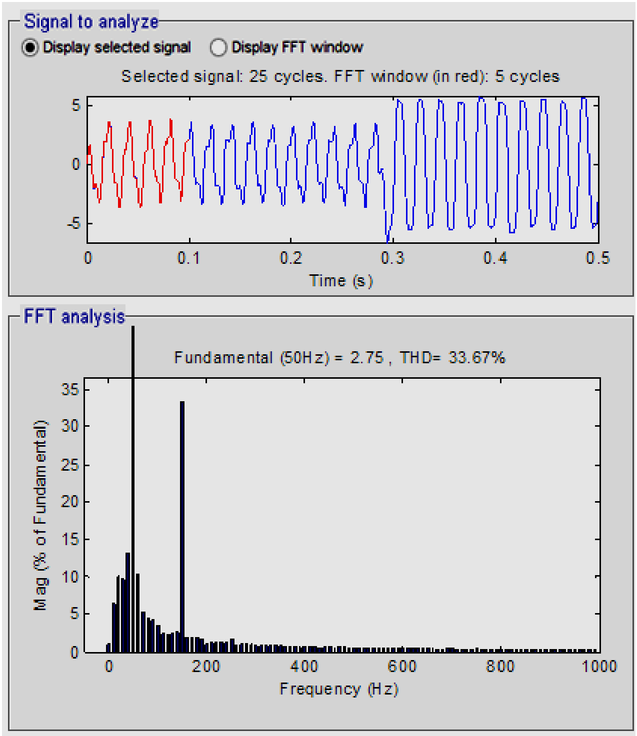

Fig 11. THD analysis – Current

## A. DPFC using ANN

The voltage infused by the arrangement converter utilizing ANN is appeared in fig 12 and the voltage and current at the Δ-side of the transformer are appeared in Fig 15. Figs 13 and 14 demonstrate the essential segments of arrangement infused voltage and line current separately. It is seen from Fig. 12 that the voltage infused by arrangement converter is a heartbeat width balanced (PWM) waveform containing two recurrence parts. The abundancy of the waveform speaks to the dc-capacitor voltage at the line side of the transformer.

The Fast Fourier Transform (FFT) investigation is performed on converter voltage appeared in Figs 16 to 18 utilizing FFT device accessible in Matlab to quantify the basic voltage infused by arrangement converter.

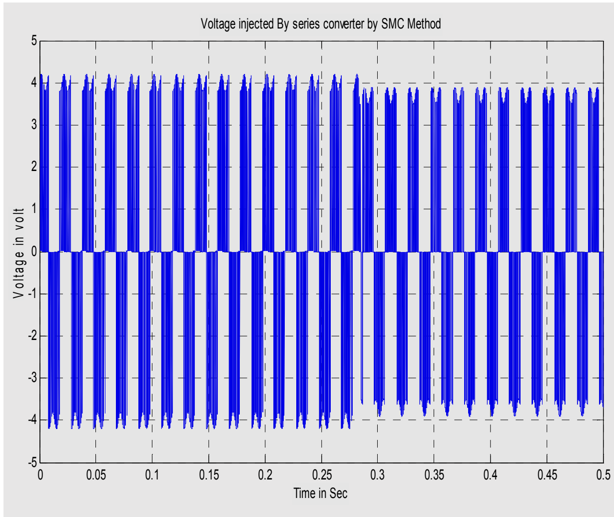

Fig 12. Voltage injected by series converter

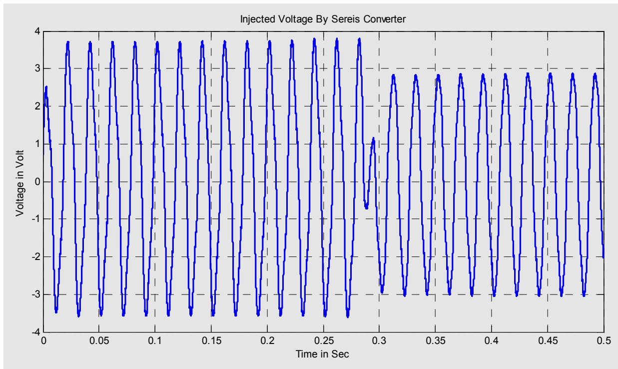

Fig 13. Injected voltage by series converter.

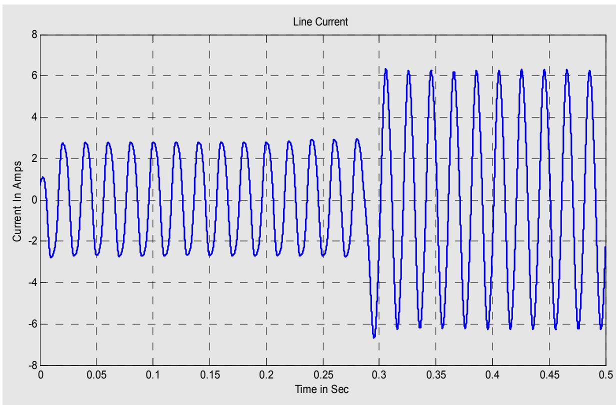

Fig 14. Line current.

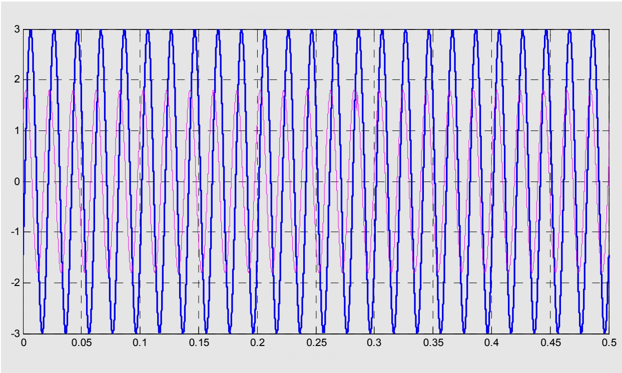

Fig 15. Voltage and current at the delta side.

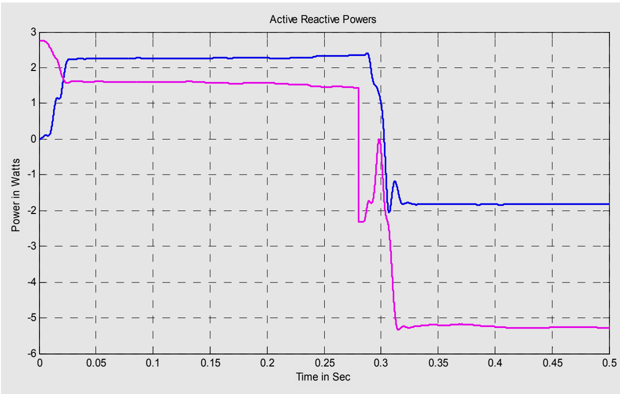


Fig 16. Active and Reactive power

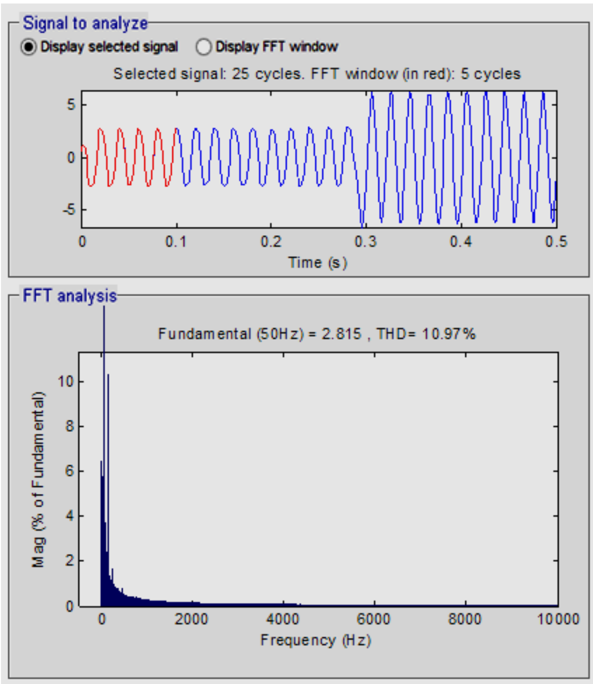


Fig 17. THD analysis - Voltage.

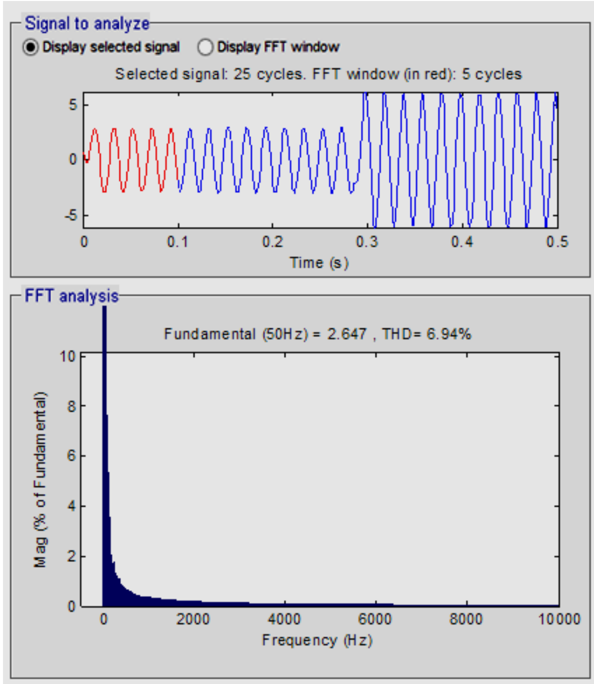


Fig 18. THD analysis - IREC.

## VI. CONCLUSION

The DPFC is utilized for transmission system in this paper with two different control strategies namely traditional PI based and ANN based controllers. The performance response in terms of system dynamics is improved by using controller. Another remarkable feature of the controller is that the line voltage present of the series converter is regulated. The harmonic analysis of the current and voltage waveforms demonstrate the effectiveness of the proposed control strategies. The simulation study is generally carried out in Matlab/Simulink environment and inferred that ANN based controller outperforms the traditional PI controller.

| | PI | ANN |
|---|---|---|
| Series inject Voltage (Ist And 3rd) Component | 78.9% | 78% |
| Fundamental injected voltage | 14% | 13% |
| Line Current | 12.96% | 11% |
| Current at receving end | 7.68% | 7.1% |

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